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Modeling and evaluation of the wind power industry chain: A China study

Zhen-yu Zhao [a,*], Yu-xi Tian [a], George Zillante [b]

[a] Department of Engineering Management, North China Electric Power University, Beijing 102206, China
[b] School of Architecture, Landscape Architecture & Urban Design, The University of Adelaide, Adelaide 5005, Australia

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ABSTRACT

The wind power industry is a complex industry involving many different types of enterprises from diverse fields loosely working together to form both internal and external associations. As a complicated system it is necessary to detect the location of the various industry components, their operation characteristics and the various relationships between the many sectors of the wind power industry. Using the general industry chain theory, this paper develops a wind power industry chain model and examines the operation mechanisms of the industry. This leads to the establishment of three perspectives for the wind power industry, these are the supply chain model, the technology chain model and the value chain model that respectively reflect the supply–demand relationship, technology transfer and value creation of wind power related industries. The models can be used to analyze: the resources distribution, the supply and demand and production relationships amongst related enterprises, the relevant technology systems and the value increase process of the wind power industry. Using China's wind power industry as an example, this study uses: (1) the supply chain to analyze the construction, equipment supply and the on-grid connection of wind power; (2) the technology chain to evaluate the technical status of China's wind power industry from the perspective of the level of technology, the source of the technology and the technology standard; and (3) the value chain to analyze the value distribution of China's wind power industry. The results suggest that over capacity, lack of core technology and an incomplete follow up service system are the major obstacles to China's wind power industry development. The models form an effective tool to analyze and evaluate the development status of the wind power industry in different countries, and support the concept of formulating a sustainable development strategy.

Contents

* Corresponding author. Tel.: +86 10 61773150; fax: +86 10 80796904.
E-mail address: zhaozhenyuxm@263.net (Z.-y. Zhao).

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1. Introduction

With fossil fuel energy resources becoming increasingly depleted and with the specter of climate change on the horizon, there is an increasing global trend towards the development of more renewable energy. Wind power generation has become recognized globally as a renewable energy technology with a large-scale commercial development value. According to the wind power market data published by the Global Wind Energy Council (GWEC), the new installed capacity of global wind power was 40.6 GW in 2011 and the total global wind power installed capacity was 237.7 GW. Globally some 75 countries are using wind power as a commercial operation with 22 of these countries having an installed capacity over 1000 MW [1]. In China, wind power development has become an important part of the national sustainable development strategy. By the end of 2011, China's wind power installed capacity increased by a further 17.9 GW, accounting for 44% of the total global increment. Thus, China's wind power installed capacity with 62.3 GW maintained its world leading position [2].

Wind power development involves a wide range of industries including consulting, research and development, manufacturing, construction, operation and electric power transmission. All of these form a type of industry chain based on their supply relationships and economic and technical links. Analyzing the industry chain model can do more than reveal its operational mechanisms and external environment; it also helps to better understand the development characteristics and competitiveness of the wind power industry.

Based on the characteristics of each link in the wind power industry, this paper builds a wind power industry chain model and analyzes its components and their relationships. The aims of the study are to gain an understanding of the current development status of China's wind power industry, to determine the problems in each link and to provide a reference for enterprises to use when determining their sustainable development strategy.

2. The wind power industry chain

2.1. Industry chain

The industry chain can be used to describe an enterprise's cluster structure in a certain industry according to their internal relationship and value adding process [3]. The enterprises in an industry chain can be divided into three separate streams namely, upstream, midstream and downstream. In general, the upstream enterprises deliver products and services to the mid steam and downstream enterprises thereby reflecting the resource processing and value creation processes. The downstream enterprises, on the other hand will deliver feedback information to the upstream and midstream enterprises. The length of the industry chain represents the level of segmentation of the industry and the depth of resources processing.

This paper describes the wind power industry chains according to their different characteristics as shown in Table 1.

2.2. The wind power industry chain model

The wind power industry chain involves wind power generation enterprises, the downstream electricity transmission and distribution enterprises and also the upstream raw material suppliers, equipment manufacturers and the related consulting services enterprises. The development of the wind power industry has led to the formation of an industry chain where its components form a complete and dynamic cycle i.e. the upstream enterprises provide products and services to the downstream enterprises; while the upstream enterprises obtain feedback information from the downstream enterprises. This process helps to promote the development of the wind power industry chain. This paper proposes the following model (see Fig. 1) for the wind power industry chain.

2.3. Classification of the wind power industry chain

The wind power industry chain provides a general description of the industry distribution (various components) and cooperation relationships amongst the enterprises. To understand the essence of the wind power industry chain, it is necessary to subdivide it into its various components. From the perspective of product supply, technology transfer and value creation, this paper divides the wind power industry chain into the supply chain, the technology chain and the value chain. The supply chain is the foundation and visible expression of the industry chain; the technology chain shows the connection between the core and general technology whereas the value chain provides the process of value adding and goal achievement of the industry. Table 2 provides a detailed comparison analysis.

This paper uses the Chinese wind power industry as a study to establish the supply chain model, the technology chain model and the value chain model thereby analyzing the current development situation and problems facing the wind power industry in China. By learning from China's experience, these models and studies will provide references for other countries to use, analyze and improve their wind power industry.

Table 1
The characteristics of wind power industry chains [4–6].

Factor	Type	Characteristics
Dominating factor	Technology leading	The core technology is the key to the formation and development of the wind power industry chain and influences the competitive advantage of the industry.
Driving force	Policy-induced	The government policies affect the formation and change of the wind power industry chain.
	Market-driven	The increase of market demand drives the development of the industry chain.
Formation mode	Connection	Connecting different industry departments in different regions with different forms of cooperation.
	Extending	Extending the existing industry chain.
Internal structure	Linear and network correlation	The professional division, knowledge linkage and modular production form a linear networked structure of the wind power industry chain.

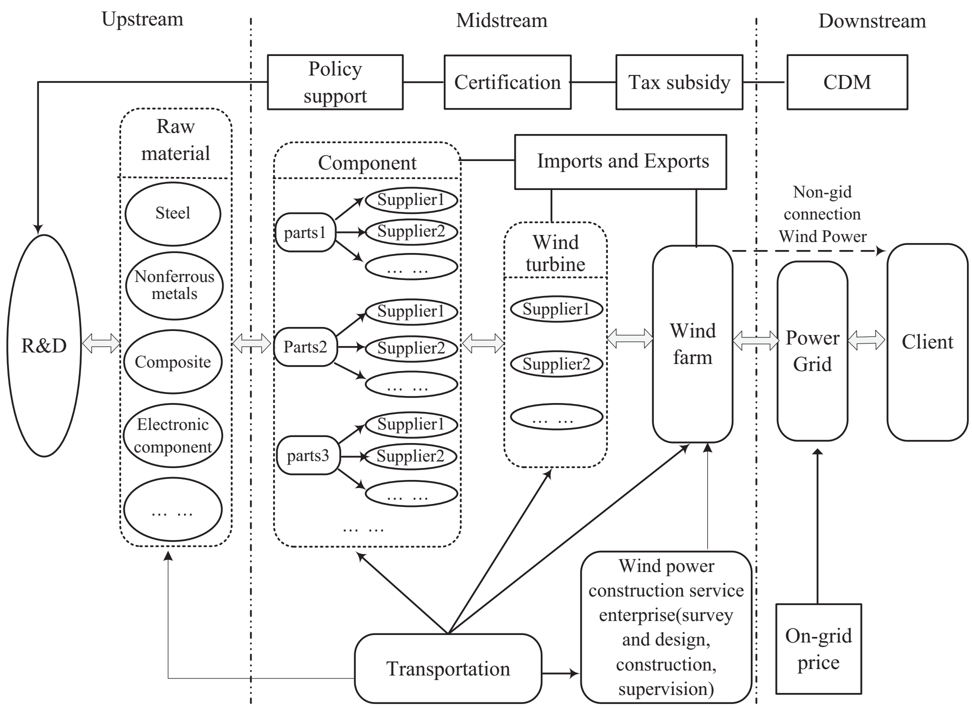


Fig. 1. Structure model of the wind power industry chain. Developed by the authors based on [7–10].

Table 2
Classification of wind power industry chains [11].

Type	View	Subject	Contents	Purpose
Supply chain	Product supply and demand	Resources supply and demand relationship	Coordination and cooperation among enterprises	Ensure smooth functioning of the industry chain
Technology chain	Technical and economic association	All of the technology in industry	Intensive degree of industrial technology	Understand the technical features and barriers of each link
Value chain	The value adding process	All link for value creation	Value added activities in every link	Find the most valuable link and improve competitiveness

3. The supply chain of the wind power industry

3.1. The supply chain model of the wind power industry

Based on extensive literature reviews about the Chinese wind power industry [12–15], this paper has established a supply chain model for the wind power industry as shown in Fig. 2. The supply chain describes the contractual relationships of the product supply and demand amongst the various industry sectors. Products and information are transferred along the supply chain in accordance with the principle of supply and demand. The chain model highlights the product supply process which includes raw material supply, equipment manufacturing, wind plant construction, electricity generation and connection to the power grid.

3.2. Analysis of China's wind power industry supply chain

3.2.1. Wind power construction and investment

In recent years, the Chinese government has attached great importance to the development of a renewable energy industry and has published a series of policies and regulations, such as the Renewable Energy Law to promote the development of the wind power industry. As indicated in Fig. 3, the last 10 years have seen that the installed capacity of wind power undergoes a significant growth in China.

China's wind power industry has formed a relatively complete product supply chain. By 2011, 30 provinces had constructed wind plants in mainland China, of those nine had an installed capacity of more than 2 GW. With respect to equipment manufacturing, China

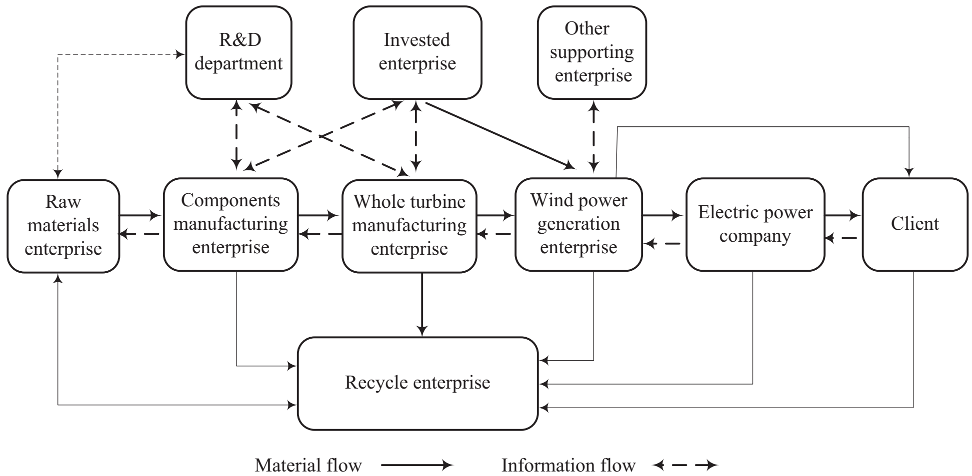


Fig. 2. The Supply chain model of the wind power industry. Developed by the authors based on [12–15].

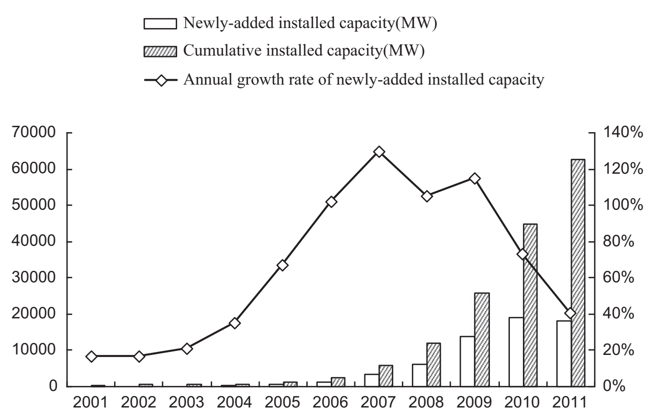


Fig. 3. Newly-added and cumulative installed capacity of wind power and growth rate in China from 2001 to 2011 [2].

has the ability to mount large-scale production for 600 kW, 750 kW and 1.5 MW capacity wind turbine generators; in fact it is now commencing production of wind turbine generators with capacities exceeding 2 MW [12]. Generally, the production capacity of wind turbines in China can meet the demands of the Chinese market with 95% of this being met by locally (Chinese) produced parts and components (localization rate). However this production capacity is out of kilter with wind turbine assembly and wind plant construction which sees the involvement of far too many enterprises e.g. there are more than 80 wind turbine enterprises and 50 blade enterprises in China.

3.2.2. Core components production

The weak manufacturing capacity for some core components has become a bottleneck for the wind power industry in China. Blades, gearboxes, generators, bearings and converters are all important parts of wind power equipment. Local Chinese manufacturers have the capacity to independently develop and produce blades, gearboxes, generators, and wind turbines below the MW grade capacity and have a complete parts and components supply system in place to support this. However, principal axis bearings, converters and core components of wind turbine above the MW-scale are all dependent on supply from foreign manufacturers because the core technologies required to produce them are not readily available in China. Similarly, importing key parts generally involves long ordering cycles and high prices e.g. China often purchases bearings from SKF (Svenska Kullager-Fabriken) in Sweden and the order cycle time often takes a year, which obviously extends the production cycle [13]. Table 3 lists the main manufacturers of wind power equipment in China.

3.2.3. Supply of wind turbines

Wind power turbine manufacturing has developed rapidly in recent years driven mainly by the construction of a large number of wind plants. In 2011, there were four Chinese local companies in the 10 largest wind power turbine manufacturers in the world. Sinovel ranked 2nd and had an 11.1% share of the global wind power market; Goldwind, Dongfang Electric and United Power respectively ranked in 4th, 7th and 10th, with market shares of 9.5%, 6.7% and 4.2% respectively (see Table 4). Moreover, the first independently (Chinese) developed 6 MW wind turbine has recently been produced by Sinovel. Currently this is the largest capacity single machine wind turbine in commercial operation in China and demonstrates that Chinese local manufacturers have reached the world standard in being able to process and assemble large capacity wind turbines.

However, wind power turbine manufacturing in China is now showing signs of both overcapacity and somewhat disorderly competition mainly due to the rapid expansion of productivity [18]. It is estimated that the overcapacity rate of wind turbine manufacturing now exceeds 50% [19]. Consequently, the price of wind turbines has fallen sharply in recent years causing a significant decline in profits with some manufacturers even reporting losses. Statistics indicate that compared with the previous year, the income of the 20 major listed wind power companies in China increased 11.3% while their net profit decreased 19.4% in 2011 [20]. Table 5 shows the profit situation of China's major wind turbine manufacturing companies in 2011. The leading enterprises: Sinovel, Goldwind and Mingyang wind power appear to have suffered a profit reduction of more than 50%.

3.2.4. Wind power generation and grid connection

In recent years, the development of grid planning and its construction has lagged behind that of wind power construction thereby hampering access to the grid and reducing the amount of wind power that can be connected to the power grid. Because of the unstable and intermittent nature of wind power, the existing grid cannot absorb large scale amounts of wind power resulting in waste of resources as more than 25% of wind turbines have to stay idle. Data from CWEA (China Wind Energy Association) shows that in 2011 there were about 10 billion kWh wind power losses due to

Table 3
Main manufacturers of wind power equipment in China [16].

Equipment	Typical manufacturers
Blades	Sinomatech Wind Power Blade, Zhuzhou Times New Material Technology, AVIC Huiteng Windpower Equipment, Lianyungang Zhongfu Lianzhong Compass Group, Tianjin Dongqi Wind Turbine Blade Equipment.
Gearboxes	Nanjing High-Speed & Accurate Gear Group, Chongqing Gearbox & Machinery, Hangzhou Advance Gearbox Group, Ningbo Donly Transmission Equipment.
Generators	XEMC Windpower, Zhuzhou CSR Electric, Yongji Xinshisu Electric Equipment.
Bearings	SKF (*Sweden*), Tianma Bearing, Luoyang LYC Bearing.
Converters	ABB (*Switzerland*), Emerson (*USA*), Vacon (*Finland*), Jiuzhou Electric.

Table 4
Top 10 wind turbine manufacturers and their market share in the world in 2011[17].

Rank	Manufacturer	Market share (%)
1	Vestas (*Denmark*)	14.8
2	Sinovel (*China*)	11.1
3	GE (*USA*)	9.6
4	Goldwind (*China*)	9.5
5	Enercon (*Germany*)	7.2
6	Suzlon (*India*)	6.9
7	Dongfang Electric (*China*)	6.7
8	Gamesa (*Spain*)	6.6
9	Siemens (*Germany*)	5.9
10	United Power (*China*)	4.2

Table 5
Profit situation of China′s major wind turbine manufacturing companies in 2011 [20].

Companies	Net profit (million yuan)	Profit growth rate (%)
Sinovel	775.72	−72.84
Goldwind	606.71	−73.50
Mingyang wind power	292.99	−58.27
XEMC Windpower	139.01	−35.96
Shanghai Electric	3310.08	17.40
Dongfang Electric	3056.23	18.60
YinXing Energy	49.04	54.60
HUAYI ELEC	59.91	−48.65

power brownouts in China. CWEA obtained this data by selecting three to five units to represent the average level of wind power plant with no power brownouts conditions as benchmark units. They then estimated the theoretical total output of the whole wind power plant according to the actual output of the benchmark units. Although this theoretical total output is an estimated value, it is relatively accurate and is thus an appropriate measure for this situation. Based on the standard coal consumption of 330 g/kWh for power generation (China Electricity Council 2011) [2], this wind energy loss is the equivalent of more than 3.3 million tons Standard Coal Equivalent (TCEs). Table 6 shows the wind power brownouts for some provinces in China in 2011, among them, Gansu has the highest power brownouts proportion of 25.25%, followed by Inner Mongolia with 23.10%, and Jilin with 21.02%. By 2012, power brownouts in China had doubled and lost output reached 20 billion kWh. In addition, the average utilization hours of wind power declined compared with those of 2011. In particular, wind power utilization hours in some provinces dropped to 1400 hours. According to the statistics published by the National Energy Administration of China in 2012, Northeast China, including Inner Mongolia, Liaoning, Jilin and Heilongjiang, faced the most serious power brownouts [21], with the power brownouts of the four provinces accounting for about half of the total national power brownouts.

Table 6
The wind power brownouts of main provinces in China in 2011 [2].

Province	The wind power installed capacity (MW)	Theoretical total output(10^8 kWh)	Lost output (10^8 kWh)	Loss rates (%)
Gansu	2102.60	43.33	10.94	25.25
Inner Mongolia	7647.25	142.25	32.87	23.10
Jilin	1187.00	22.60	4.75	21.02
Heilongjiang	1551.20	31.17	4.48	14.39
Liaoning	2181.00	37.32	3.90	10.45
Xinjiang	597.30	13.39	0.70	5.20
Yunnan	325.50	4.90	0.24	4.90
Hebei	2370.50	46.14	1.78	3.86
Shandong	601.25	8.71	0.10	1.17
Guangdong	127.75	3.66	0.04	1.00
Total	18691.35	353.47	59.80	16.92

3.2.5. Supply–demand balance analysis

Supply–demand balance is a prerequisite for the sustainable development of the wind power industry chain. In view of the current contradiction between wind power supply and demand, China needs to seriously consider speeding up grid infrastructure planning and construction and resolve the connection and absorption issue of wind power. The wind resource rich regions of northern China could absorb the excess wind power available to replace their coal fired boilers and supply heat during the winter months.

Because of the intense competition in the Chinese wind turbine market, Chinese manufacturers should consider a “Going out” strategy and try to enter their products into the overseas market. Currently, Chinese manufacturers are in the initial stages of exporting with a small number of wind turbines being shipped to a few countries. Compared to European countries, Chinese manufacturers have exported fewer lower capacity single units with comparatively lower level of technology [22]. For example, the overseas income for Goldwind and Sinovel accounted for only 9% and 1% of their gross income respectively. Similarly, offshore wind power is in its infancy in China and China should seriously consider exploiting this form of offshore wind power in the future as another product in its armory of wind power [23]. Chinese equipment manufacturers ought to improve their independent ability to conduct research and development and gradually reduce their dependence on foreign manufacturers.

4. The technology chain of the wind power industry

4.1. The technology chain model of the wind power industry

Technology is important for the development of the wind power industry. In the development process of the industry, various related techniques are linked sequentially and form an industrial technology chain. The technology chain indicates that different products are mutually linked by technologies and that

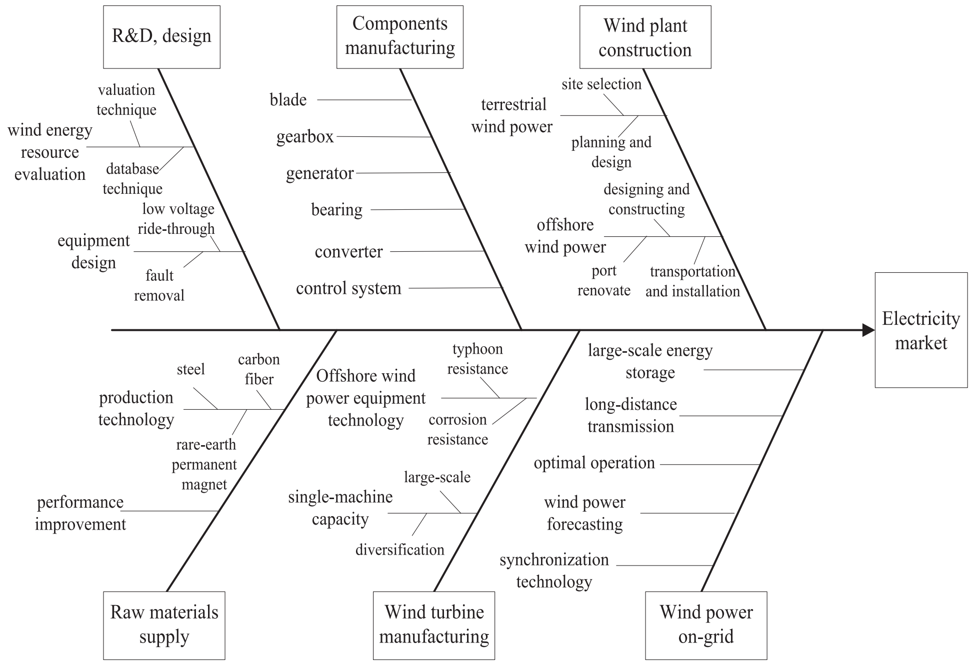


Fig. 4. Technology chain model of wind power industry. Developed by the authors based on [24–26].

there are also some connections between various technologies i.e. to obtain and use a kind of technology may have another technology as a prerequisite [24,25]. The wind power industry is a technology diverse industry that includes meteorology, aerodynamics, material science, chemistry, environmental sciences, structural mechanics, mechanical processing technology, construction technology, computer technology, control technology, mechatronics engineering, electrical engineering and so on [26]. This paper has established the technology chain of the wind power industry as a fishbone diagram (see Fig. 4). The technology chain can aid the understanding of the overall technology structure and provide a basis for the comprehensive analysis of both the status quo and the deep seated problems that may exist in the wind power industry in China.

4.2. The development status analysis of the technology chain for China's wind power industry

4.2.1. Technology level

Wind power technology can be divided into small, medium and large-scale wind power technology.

Small and medium-sized wind power technology has been the mainstream technology used for both the distribution and independent generation of power in China. With improvements in technology China's small and medium-sized wind power technology has matured and undergone significant increases in application. The wind power technology has also combined with photoelectric technology to form a solar and wind hybrid technology for which it has retained independent intellectual property rights [27]. China has also mastered some technologies at the international advanced level e.g. low wind speed starting, low wind speed generation and pitch-controlled system technology.

With regards to large-scale wind power technology, China has now mastered the manufacturing technology for MW-scale wind turbine generators and their main components and has also been able to achieve mass production [28]. For example, Sinovel's 3 MW, 5 MW and 6 MW double-fed wind turbines and Goldwind's 3 MW direct-drive wind turbines have all reached the international advanced level. However, when compared to the leading global levels, Chinese large-scale wind power technology is still some way off achieving maturity as examples, (1) China's wind power equipment manufacturers still lack the design and manufacturing technology for some key components, such as principal axis bearings, converters and machine control systems [29]; (2) Technology support for offshore wind power in China is also weak. China lacks research trial experience for offshore wind turbines and the special construction machinery and equipment required to install wind power facilities in the ocean; (3) The technology level for offshore substations and submarine cable transmission is low [30,31]. Offshore wind power development is gaining more attention in China and if it is to be seen as a major source of wind power for the country serious attention should be given to increasing research and development efforts into offshore wind power related technologies and equipment, including turbines, construction and installation, operation and maintenance, grid connection technology and equipment and technical standard, etc [32].

4.2.2. Technology source

During the last few years, China has had some great achievements in wind power equipment manufacturing and has realized its localization potential. China's wind power equipment manufacturers now have several ways to obtain wind turbine technology i.e. they can introduce, digest and absorb foreign technology, they can purchase a production license or they can engage in a joint-design arrangement or partake in joint-ventures [33,34]. There are several different types of imported wind turbine technologies, ranging from 600 kW to 3600 kW, with the 1500 kW turbine technology being the most popular. The top three wind turbine manufacturers in China namely Sinovel, Goldwind and Dong Fang Turbine, imported 1500 kW wind turbine technology from Germany. Similarly, Sinovel developed 3000 kW wind turbine technology jointly with Wentec (Germany) whereas Dong Fang Turbine imports 2500 kW technology from Wentec (Germany) [22]. Table 7 lists the main technology sources of China's wind power equipment manufacturers [35]. The majority of the enterprises still do not have the ability to independently develop and design the entire wind turbine. Many enterprises paid high license fees but did not have the “pricing rights” of key components and were thus limited to a small area of

Table 7
The main sources of technology for China's wind power equipment manufacturers [35].

Technology source	Examples
Purchase foreign design and technology or engage in joint research with leading international enterprises	Goldwind 1.2 MW and 1.5 MW direct-drive wind turbine, Mingyang wind power 1.5 MW doubly-fed wind turbine
Purchase foreign mature wind power technology and obtain licenses to produce in the domestic market	Goldwind 600 kW and 750 kW wind turbine, Zhejiang Windey 750 kW wind turbine, Sinovel and Dongfang Electric 1.5 MW unit
Form Joint Ventures with foreign companies to attract foreign mature technology	CASC-Acciona and Nordex wind power 1.5 MW wind turbine, XEMC 2 MW wind turbine
Foreign wind generator manufacturer establish an individual proprietorship in China to design and produce	850 kW Gamesa unit, 1250 kW Suzlon unit, 1.5 MW General Electric unit, 2 MW Vestas unit
Domestic universities and companies self-design	Zhejiang Windey, SANY, Shanghai Wande, China Creative wind energy 1.5 MW wind turbine

Table 8
The main wind power technology standards in China [37].

Serial number	Standard code	Drafted by
GB/T 19963-2011	Technical rule for connecting wind farm to power system	China Electric Power Research Institute
NB/T 31003-2011	Design regulations for large-scale wind power connecting to the system	China Power Engineering Consulting Group Corporation
NB/T 31004-2011	Guidelines for vibration condition monitoring and diagnose of wind turbine generator	Zhong Neng Power-Tech Development Co., Ltd.
NB/T 31005-2011	Measurement standard of wind farm power quality	China Electric Power Research Institute
NB/T 31006-2011	Technical code for anticorrosion of offshore wind farm steel structures	Nanjing Hydraulic Research Institute
NB/T 31018-2011	Wind turbine generator system technical specification of electric pitch system	China Electric Equipment XuJi Electric Co., Ltd.
Q/GDW 588-2011	Functional specifications for wind power forecasting	China Electric Power Research Institute
Q/GDW 432-2010	Specification for wind power dispatching and operating management	China Electric Power Research Institute

the market for sales. Collectively these issues have hindered Chinese manufacturers from entering the overseas market.

4.2.3. Technology standard

It was not until 2010 that the Chinese wind power industry began to formulate its own technical standards system. By the end of 2011, 41 wind power technology standards had been issued. These included: wind power planning design system standards, wind power construction and installation system standards, wind plant operation and maintenance management system standard, wind power on-grid management technology system standards, wind mechanical equipment system standard and wind power electric equipment system standards [36]. In addition, two standards including: "wind turbine low voltage across ability test procedures" and "wind power grid connected performance evaluation methods" are currently under examination for approval, while another six standards are being drafted. Table 8 lists the main wind power technology standards [37]. The new standards system should help to provide the impetus for the promotion of a healthy and sustainable wind power industry for China.

The Chinese wind power technology standards, inspection procedures and certification systems are still in their infancy [38]. Some enterprises have only certified wind turbines and core components and have neglected the inspection of raw materials and the more common components. The wind power industry is a complicated industry system and involves many fields and various technologies. Technology problems and improper operation of any link will affect the ultimate wind power quality. Accordingly, in order to ensure good quality products it is necessary for China to put in place a comprehensive technology inspection and certification system.

5. Value chain of the wind power industry

5.1. Value chain model for the wind power industry

The Value chain describes the value transfer and value-adding process that occurs when we convert from raw materials to a final product or service. The enterprise is not only the producer and seller, but also the value creator and transmitter. The value chain consists of a series of business processes, where each can be divided into a number of specific works. The creation of value for an enterprise consists of two activities, i.e. basic activities and supporting activities. Basic activities refer to those direct activities involved with production such as design, manufacture, process, assembly, construction, and operation. The supporting activities involve functions such as planning, financing, purchasing, research and development, personnel management, training and service [39]. All these activities are closely interlinked and form the value chain of an industry.

This paper proposes a value chain model for the wind power industry as shown in Fig. 5. This model classifies wind power equipment design, raw material supply, parts processing, wind turbine assembly, wind plant construction and wind power on-grid connection as the basic activities, and those such as procurement, research and development, personal administration and policy of each link as the supporting activities. The value chain of the wind power industry assists in determining the value increase process of related activities. It also assists with the analysis of resource optimization, competitive advantages and development strategy for the industry.

5.2. Development status analysis of the value chain for China's wind power industry

5.2.1. Value distribution

The wind power industry is a technology-intensive industry, with the major value increase sectors being in the design stage and in the after-sales service stage. The value distribution of the whole industry chain is represented by a "smiling curve" graph as shown in Fig. 6. Currently, most enterprises in China only have an assembly manufacturing ability and lie in the bottom part of the "smiling curve" which is the weakest value added sector of the wind power industry. China needs to change direction from emphasizing development speed to cultivating industry core competitiveness. With the global wind power market competition increasing, China's wind power enterprises need to examine their

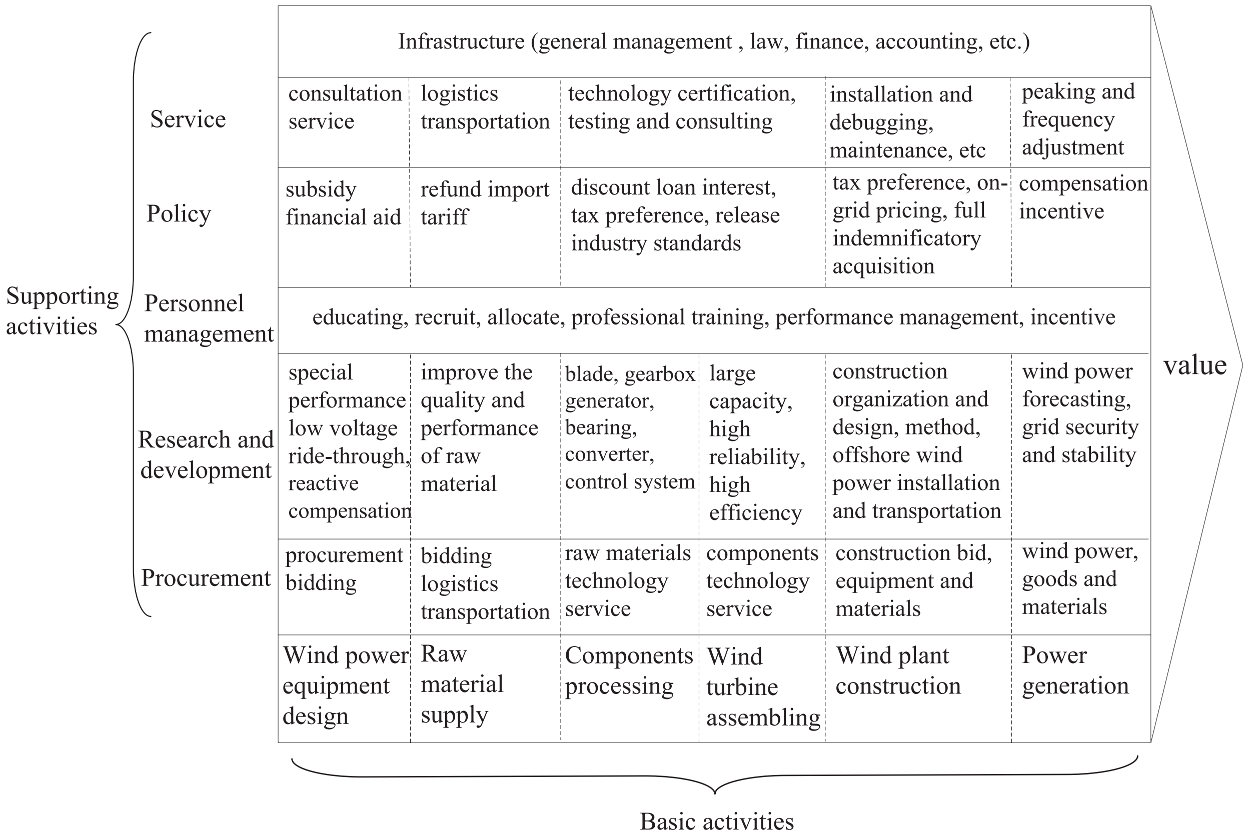


Fig. 5. Value chain model of wind power industry. Developed by the authors based on [39,40].

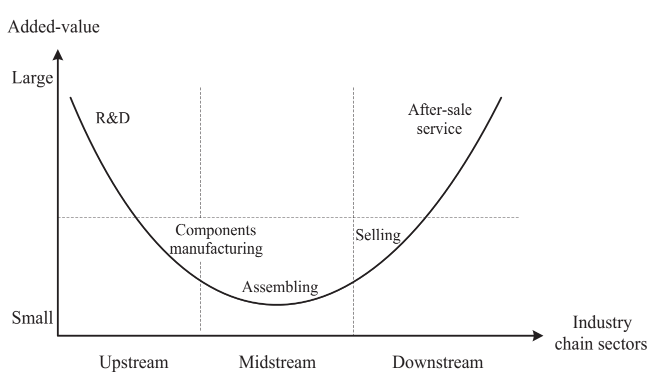


Fig. 6. "Smiling curve" representation graph of value distribution Developed by the authors based on [41,42].

positions in the process of the value chain according to both market requirements and the development of competitors, and try to locate opportunities in the wind power industry value chain based on their own advantages.

5.2.2. Wind power policy

Policy plays an important role in the growth of the wind power industry. The encouragement of a wind power policy can create a favorable environment for wind power investment and development and factors that encourage such a policy will have a positive impact on the value chain of the wind power industry. From 2004, China began formulating a series of laws and regulations to promote the development of the wind power industry. Of particular note was the 2005"Renewable Energy Law", the first such law in China, which was published and implemented and immediately provided both legal protection and opportunity for the development of the wind power industry. Consequently, the proportion of the installed capacity of renewable energy within the total installed capacity has undergone significant expansion since 2006 [43]. The "Renewable Energy Law" also acted as a guide for the introduction of a series of incentive policies and regulations related to renewable energy, such as tax reductions and exemptions, total acquisition of electricity produced by the wind power plant and by the power grid, preferential on-grid pricing for power generation enterprises, favorable loans and financial subsidies. [44]. Meanwhile, the central budget established a "Renewable Energy Development Special Fund" and provided fiscal preferential loans for the research and development (R&D) and utilization of renewable energy, which in turn helped stimulate enterprises into improving their ability for independent innovation. In addition, the Renewable Energy Law of 2006 stipulated that all grid corporations were mandated to sign agreements with those renewable energy power plants to purchase the entire amount of the grid-connected renewable energy and to also provide grid connection services [45]. With the growth of the wind power industry, some local laws and regulations were also issued to endeavor to further encourage investment in wind power.

Wind power is a newly emerging industry, accordingly Chinese wind policy need to be cognizant of this and maintain a degree of adaptability and flexibility. For example, the electricity price is a key factor that influences wind power investment and the market. With this in mind the Chinese government has constantly adjusted and modified the electricity price policies for wind power to ensure that they would be able to satisfy the different requirements in each of the different wind power development stages. The evolution of wind power price policies is shown as in Table 9.

Unfortunately, China does not have a complete wind power policy system, consequently there is still a lack of a stable mechanism to support the development of the wind power industry.

Table 9
The evolution process for electricity pricing policies for wind power in China [28,46].

Stage	Year	Type of wind power price	Description
I	1990s to1998	Competition with coal fired power price	The grid connected wind power price refers to the local coal fired power price.
II	1998 to 2003	Government approval price	The grid connected wind power price is approved by the local price department.
III	2003 to 2005	Both of the bidding price and approval price	Large-scale wind plant use bidding price, while small and medium wind plant use approval price.
IV	2006 to 2009	Bidding and approval price	Wind power price is decided by open competitive bidding.
V	2009 to present	Fixed benchmark price	China is divided into four types of wind energy resources areas, each areas has different wind power benchmark price.

In addition, some policies lack the supporting rules for implementation and are not effective. Accordingly, there is a need for China to constantly improve its wind power development policies in order to increase the value of the wind power industry chain.

5.2.3. Professionals cultivation

The shortage of wind power professional talent is one of the main factors hindering the development of the Chinese wind power industry. China has a serious deficiency in terms of wind power professional talent, especially with respect to wind turbine R&D professionals, senior management personnel, manufacturing professionals, senior technicians and wind plant operation and maintenance personnel. The main reason appears to be the lack of a reasonable professional cultivation system. Given the lack of a professional mentoring base for wind power professional talent most technical staff engaged in wind power R&D, design, manufacturing and installation and operation management have come from other areas and generally lack adequate professional training about wind power [47]. As a relatively new energy subject area wind power generation requires a group of integrated elite innovative professionals with practical experience of wind power projects and with a thorough understanding of wind power theory.

With wind power increasing its market share the issue of lack of suitable wind power professionals will become more acute. According to China's national energy planning guidelines, by 2020, wind power installed capacity will reach 150 GW in China [48], thereby exacerbating the need for a large number of senior professionals. Currently, only 16 universities in China have established bachelor degrees in wind power engineering to train undergraduates e.g. North China Electric Power University, Hohai University, Hebei University of Technology, and Northeast Dianli University [49]. In 2006, North China Electric Power University enrolled the first group of wind power professional undergraduate students i.e. a total of 30 with a plan to increase those enrollments annually and by 2012, enrollments expanded to 70. Nevertheless, the present situation cannot meet the market demand. The mentoring and cultivation of wind power professionals is a long-term systematic project and the state, society, universities and enterprises need to cooperate in order to produce an adequate number of professionals to properly develop the Chinese wind power industry.

5.2.4. Services system of wind power industry

Good service is a sought after quality in the wind power industry and can add value to enterprises. Service can assist enterprises to create more profits in the short term. In the wind power industry, services such as consultation service, after-sales service and problem resolution can help enterprises to build a brand and expand their competitive advantage. Taking equipment manufacturing for example; the selling of equipment is a one-time activity however maintenance service is continuous. Good service is not only a source of profits, but can also assist the enterprise gain a better reputation. However, the development of China's wind power industry has had an excessive dependence on producing products with an incomplete service backup system. The relevant services system has been developing slowly. Wind power planning and design, power prediction, equipment transportation, construction and installation, reconditioning and maintenance, operation management, are all fields that lack a corresponding professional service [50]. Hence, it is necessary to extend the newly required related services to the wind power industry in order to meet market demand and to enhance the value and to increase the ability and credibility of the industry. It should be noted that China is paying attention to this issue and the State Council recently (2013) issued advice on "How to promote the healthy and orderly development of the wind power industry." According to the document, China will establish and improve the wind power industry service system [51] which is expected to create a favorable environment for the development of the wind power industry in China.

6. Conclusion

Based on the structure and association of the wind power industry sectors, this paper has built a wind power industry chain model that can be used to, describe the interactive relationship amongst the various sectors, discover the operating mechanisms of the wind power industry and to help guide the development of the wind power industry. From the perspective of wind power products supply and demand, technology association and value creation, this paper has proposed: a supply chain model, a technology chain model and a value chain model for the wind power industry. The supply chain can be used to analyze the supply and demand relationship amongst upstream and downstream firms in the wind power industry chain and to locate the problems of resources allocation and logistics of the wind power industry. The technology chain can help to understand the technical nature and to discover the technical problem of each link of the wind power industry chain. The value chain analysis can enable enterprises to identify their positions in the wind power industry value chain and use it to establish and consolidate its competitive advantages in the industry.

China ranks first for cumulative wind power installed capacity as well as having the largest wind power market in the world. This paper used China's wind power industry as an example in applying the supply chain, the technology chain and the value chain to analyze and evaluate the development of China's wind power industry. The results suggest that, with respect to products supply and demand, the productivity of Chinese wind turbine has been able to meet the domestic demand, the majority of the parts have realized their localization advantage and the wind turbine production of the four largest Chinese wind turbine manufacturers have accounted for over 30% of the global market. Although China

has formed a complicated wind power supply chain, there are still some parts of this chain that do not function well; the main problems being: the overcapacity of the domestic wind turbine manufacturing market, the inability of the power grid construction to keep pace with the increase in number of wind power farms and the inability of large scale wind power to connect to the power grid thereby causing a waste of resources. Accordingly, speeding up the adjustment of the grid structure and enhancing wind power grid-connection technology is the priority for China's wind power industry development. By assessing the technology level, technology source and technology standard of China's wind power industry, the result suggests that small and medium-sized wind Chinese power technology enterprises have been able to achieve international advanced level status. Similarly, large-scale wind power technology has made some remarkable progress and China now has the ability to manufacture wind turbines up to 6 MW. Despite this some Chinese wind turbine manufacturers have still failed to grasp some key technologies. Given that technology is at the core of the whole wind power industry, Chinese wind turbine manufacturers should enhance their ability of independent innovation and improve their technology standard system. By analyzing the overall value distribution of the wind power industry chain, it is suggested that China should strengthen its cultivation of wind power professionals and build a complete services system to increase the competitiveness of the wind power industry. Research and Development and after-sales service will occupy more important positions in the future wind power industry of China.

This study proposes a valuable reference for analyzing and evaluating the wind power industry development status for different countries. It also provides a useful tool for the wind power industry and related enterprises to formulate sustainable development strategies. Future researchers may examine the effectiveness of these recommended models and improve them under different scenarios.

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